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**Intermountain
Forest and Range
Experiment Station**
Ogden, Utah
84401

Research Paper
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# Understory Tree Release Following Harvest Cutting in Spruce-Fir Forests of the Intermountain West

**Ward W. McCaughey
and
Wyman C. Schmidt**

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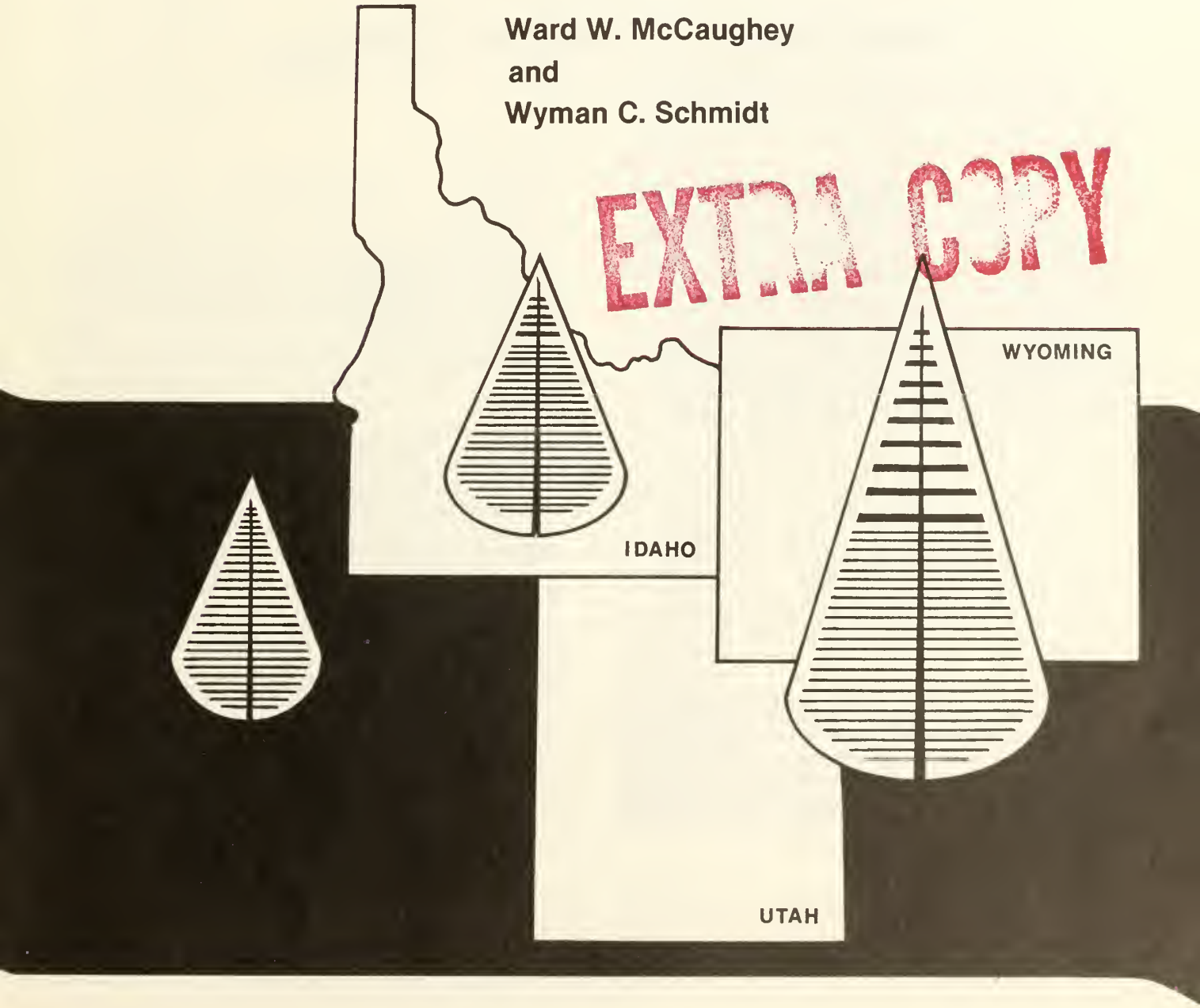

## THE AUTHORS

**WARD W. McCAUGHEY** is a forester with the Silviculture of Northern Rocky Mountain Subalpine Forest Ecosystems research work unit, stationed at the Forestry Sciences Laboratory, Bozeman, Mont. He joined this research unit in 1979. His work now focuses primarily on developing applications of silviculture to ameliorate the impact of western spruce budworm in coniferous forests of the Northern Rockies.

**WYMAN C. SCHMIDT** is a research silviculturist and Project Leader of the Silviculture of Northern Rocky Mountain Subalpine Forest Ecosystems research work unit at the Forestry Sciences Laboratory, Bozeman, Mont. Dr. Schmidt's research has focused primarily on the ecology, stand development, and silviculture of young coniferous forests of the Intermountain and Northern Rocky Mountain West

## RESEARCH SUMMARY

This study is aimed at determining height growth response of understory Engelmann spruce *(Picea engelmannii)* and subalpine fir *(Abies lasiocarpa)* trees following clearcutting and partial cutting. Understory trees, released 10 years earlier on four study areas—two in Utah and one each in Idaho and Wyoming—provided the data base. Both spruce and fir responded by substantially increasing their height growth after adjusting to their new environment—growth response was greatest in the clearcuts, intermedial in the partial cuts, and essentially missing in the uncut areas. Five-year pretreatment height growth and posttreatment basal area were good predictors of posttreatment response of the understory trees. Fir responded sooner and more than spruce on both clearcuts and partial cuts. Understory trees responded in much the same pattern throughout all four study areas.

## ACKNOWLEDGMENTS

We thankfully acknowledge the Timber Management staff of the Forest Service Intermountain Region and the staffs of the Payette, Teton (now Bridger-Teton), Uinta, and Dixie National Forests for their parts in the conduct of this study. Also, we thank Arthur L. Roe (Intermountain Forest and Range Experiment Station, retired) for designing the original cutting methods trials that provided the conditions needed for this study, Dr. Robert D. Pfister (Intermountain Forest and Range Experiment Station) for his support and help in classifying the ecological habitat types of the study areas, Al Dahlgreen (Intermountain Region, retired) for his help in establishing and conducting the original study, Orville Engelby (Intermountain Region Silviculturist) for his continuing advice and support of this study, and Gayle Yamasaki and Michael Marsden (Intermountain Forest and Range Experiment Station) for statistical help in completing this paper.

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## INTRODUCTION

Successful management of the spruce-fir *(Picea engelmannii-Abies lasiocarpa)* forests of the Intermountain West depends on rapidly and adequately regenerating cutover areas. Regeneration difficulties have plagued managers of these forests. Difficulties are generally most severe in the high elevation forests of the region in southern Utah with decreasing problems as you go north into the lower elevation forests of south-central Idaho (Roe and Schmidt[1]; Roe and others 1970). A number of silvicultural options using even- and uneven-aged management techniques are available—plant immediately, direct seed, rely on natural regeneration, retain adequate amounts of advance regeneration, or various combinations of these. Depending on the particular circumstances, each has some advantages. One of the most controversial, however, is the choice of "featuring advance regeneration." Controversy generally centers on the expected response of the advance regeneration to release. How soon, how much, or will it respond?

There are indications from other areas that understory spruce and fir will respond once released from the overwood. For example, in northeast California on the Swain Mountain Experimental Forest, red fir *(Abies magnifica)* and white fir *(Abies concolor)* developed rapidly after release even though they had been suppressed and had grown slowly for over 40 years (Gordon 1973). Ferguson and Adams (1979), working with grand fir *(Abies grandis)* understory trees in north Idaho, found that 5-year height growth before release was the best predictor of height growth after release. Also, younger trees responded quicker, short trees more than tall trees, and undamaged trees sooner than damaged trees after release. Shade from scattered residual overstory trees was initially beneficial to release but detrimental to growth after trees adjusted to the new environment. Engelmann spruce and subalpine fir understory trees also responded well following release from overwood in other studies in north Idaho (Roe and DeJarnette 1965). Information about understory spruce and fir growth response in the Intermountain West is sparse, however.

Foresters are interested in cutting methods favoring advance reproduction since advance growth provides immediate growing stock, shade for subsequent seedings, some continuity of green forests, and some soil protection. If these understory trees will not release, however, their use for these purposes is questionable. Knowing when advance regeneration should be left and when it should be destroyed to provide growing space for subsequent reproduction is important for managing these forests.

This paper reports the first 10 years of a cutting methods study started in 1967 on four National Forests in the spruce-fir zone of the Intermountain area. It describes release of advance regeneration between even-aged (clearcuts) and uneven-aged (partial cuts) management systems and provides height growth predictions for forest managers (fig. 1A, B).

[1]Roe, Arthur L., and Wyman C. Schmidt. 1964. Factors affecting natural regeneration of spruce in the Intermountain region. USDA For. Serv. mimeo rep., 68 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Figure 1.—Advance regeneration of Engelmann spruce and subalpine fir 10 years after harvest cutting treatments: A. Clearcut, Dixie National Forest; B. Partial cut, Uinta National Forest.

## METHODS

### Study Areas

Four study area locations extending from southern Utah to south-central Idaho were established in 1967. Study plots were established in 5-acre (2-ha) clearcuts, partial cuts, and control areas on the Payette National Forest in Idaho, the Teton (now Bridger-Teton) National Forest in Wyoming, the Uinta National Forest in central Utah, and the Dixie National Forest in southern Utah (fig. 2).

#### Payette National Forest

The Payette study area is near Cloochman Creek on the McCall Ranger District, at about 6,000 feet (1 829 m) elevation with a west to southwest exposure. Slopes range from 0 to 30 percent and average around 10 percent.

Soils are of granitic origin, are generally sandy loams, moderate to well drained, and slightly acid. Some of the cutting units are bisected by small streams and contain boggy areas.

Composition of the virgin stand was 77 percent Engelmann spruce, 18 percent subalpine fir, and 5 percent lodgepole pine *(Pinus contorta)*. The mature stand was over 200 years at the time of cutting.

The ages and sizes of the sample understory trees at the time of harvest on the Payette were:

| | | Average | Range |
|---|---|---|---|
| SPRUCE | Age | 37 | 6 to 102 |
| | Height (ft) | 3.4 | 0.3 to 12.1 |
| | | (1.04 m) | (0.09 to 3.69 m) |
| FIR | Age | 52 | 5 to 166 |
| | Height (ft) | 3.2 | 0.2 to 12.4 |
| | | (0.98 m) | (0.06 to 3.78 m) |

Three habitat types (h.t.) are represented on the area (Steele and others 1981):

Dry — *Abies lasiocarpa/Xerophyllum tenax* h.t., mostly *Vaccinium scoparium* phase,
Moist — *Abies lasiocarpa/Xerophyllum tenax h.t., Vaccinium globulare* phase, and
Wet — *Abies lasiocarpa/Calamagrostis canadensis* h.t., *Ligusticum canby* phase.

Average basal areas remaining after the harvest cuttings were:

| | Uncut forest | Partial cut | Clearcut |
|---|---|---|---|
| Average basal area | | | |
| $ft^2$/acre | 129.0 | 29.0 | 7.0 |
| $m^2$/ha | 29.6 | 6.6 | 1.6 |

Individual point samples ranged from 0 to 250 $ft^2$ of basal area per acre (0 to 57.4 $m^2$/ha). Remaining basal area within the clearcuts was due to residual advance regeneration.

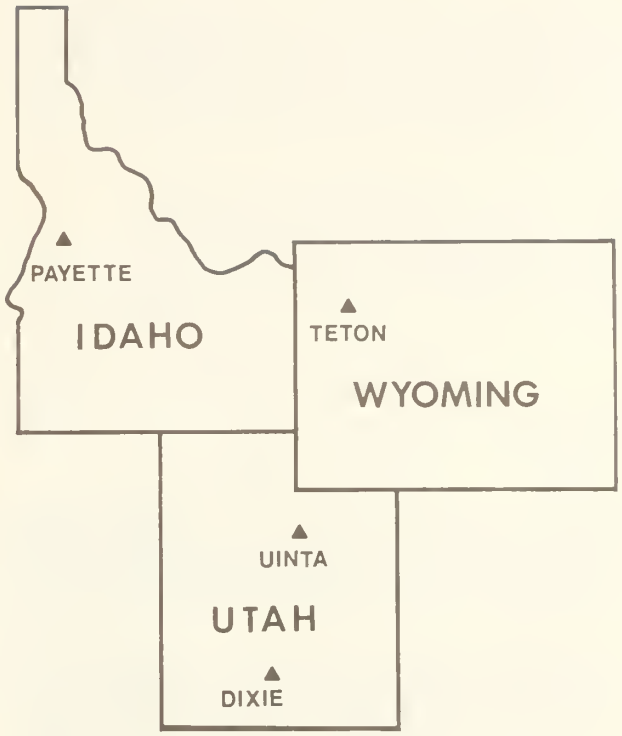


Figure 2.—Location of spruce-fir understory release study areas in the Intermountain West: Payette, Teton, Uinta and Dixie National Forests.

#### Teton National Forest

The Teton study area is located in Teton County, Wyo., near East Leidy Creek on the Gros Ventre Ranger District at approximately 8,600 ft (2 621 m) elevation on generally north-facing slopes. Slopes range from 0 to 50 percent with some pitches up to 70 percent.

Soils are derived from Mesozoic sedimentary rock—primarily limestone, sandstone, and shale. Moisture is adequate at all times of the year, and some areas have excessive soil moisture for ideal growing conditions, as evidenced by the increase of *Equisetum*. Drainage of the area varies from very poor to good.

The Teton has the largest variety of species found on any of the study areas. Stand composition was 85 percent Engelmann spruce, 8 percent subalpine fir, 3 percent lodgepole and limber pine *(Pinus flexilis)*, and 1 percent Douglas-fir *(Pseudotsuga menziesii)* at the time of harvesting.

The ages and sizes of the sample understory trees at the time of harvest were:

| | | Average | Range |
|---|---|---|---|
| SPRUCE | Age | 65 | 7 to 168 |
| | Height (ft) | 3.5 | 0.3 to 10.8 |
| | | (1.07 m) | (0.09 to 3.29 m) |
| FIR | Age | 79 | 7 to 185 |
| | Height (ft) | 3.3 | 0.3 to 14.1 |
| | | (1.01 m) | (0.09 to 4.30 m) |

Stand age of the mature overwood at the time of cutting was between 200 and 300 years old. The general stand condition was good with only minor bark beetle problems in some of the windthrown spruce.

Three habitat types were mapped on the study site (Steele and others [In press]):

Dry — *Abies lasiocarpa/Vaccinium globulare* h.t.,
Moist — *Abies lasiocarpa/Actea rubra* h.t., and
Wet — *Abies lasiocarpa/Streptopus amplexifolius.*

Average basal areas remaining after the harvest cuttings were:

| | Uncut forest | Partial cut | Clearcut |
|---|---|---|---|
| Average basal area | | | |
| ft²/acre | 132.0 | 82.0 | 1.0 |
| m²/ha | 30.3 | 18.8 | 0.2 |

Individual point samples ranged from 0 to 280 ft² of basal area per acre (0 to 64.3 m²/ha). The clearcut basal area value was due to residual advance regeneration.

**Uinta National Forest**

The Uinta National Forest study area is in Wasatch County, Utah, on the Heber Ranger District. The plots are at Wolf Creek Pass at 9,500 ft (2 896 m) elevation on a northerly aspect with slopes from 10 to 30 percent.

Soils are generally well drained on the upper slopes with soil moisture increasing toward the lower base of the study areas. Small intermittent streams bisect the area.

The mature overstory stand consisted of 95 percent Engelmann spruce and 5 percent subalpine fir. Ages and sizes of the sample understory trees at the time of harvest were:

| | | Average | Range |
|---|---|---|---|
| SPRUCE | Age | 71 | 5 to 170 |
| | Height (ft) | 3.9 | 0.2 to 12.6 |
| | | (1.19 m) | (0.06 to 3.84 m) |
| FIR | Age | 68 | 16 to 144 |
| | Height (ft) | 2.9 | 0.3 to 11.5 |
| | | (0.88 m) | (0.09 to 3.51 m) |

General stand condition was good with minimal windthrow and light bark beetle damage.

One habitat was found on the area—*Abies lasiocarpa/Berberis repens* h.t., *Berberis* phase (Pfister 1972).

Average basal areas remaining after the harvest cuttings were:

| | Uncut forest | Partial cut | Clearcut |
|---|---|---|---|
| Average basal area | | | |
| ft²/acre | 146.0 | 109.0 | 42.0 |
| m²/ha | 33.5 | 25.0 | 9.6 |

Individual point samples ranged from 0 to 230 ft² of basal area per acre (0 to 52.8 m²/ha). The large basal area value in the clearcuts was due to advance regeneration left on the site. Partial cut treatments were somewhat atypical in that they were small half-acre (0.2-ha) clearcuts randomly located throughout the 5-acre (2-ha) treatment block.

**Dixie National Forest**

The Dixie study units are located in Garfield County, Utah, on the Aquarius Plateau of the Escalante Ranger District at 10,300 ft (3 139 m) elevation on nearly level terrain.

Soils are glacial deposits overlaying basalt flows. Soils are gravelly, clay, and sandy loams, 12 to 21 inches (0.30 to 0.53 m) deep, with pH values of from 5 to 6.

Stand composition of the mature forest was 90 percent Engelmann spruce, 10 percent subalpine fir, and a few small scattered aspen *(Populus tremuloides)* clones. Overstory Engelmann spruce were even-aged while subalpine fir was uneven-aged, but not all-aged (Hanley and others 1975).

Ages and sizes of the sample understory trees at the time of harvest were:

| | | Average | Range |
|---|---|---|---|
| SPRUCE | Age | 59 | 5 to 150 |
| | Height (ft) | 3.7 | 0.2 to 14.0 |
| | | (1.13 m) | (0.06 to 4.27 m) |
| FIR | Age | 57 | 8 to 126 |
| | Height (ft) | 4.0 | 0.2 to 11.8 |
| | | (1.22 m) | (0.06 to 3.60 m) |

General condition of the mature stand was good, but many snags indicated past beetle attacks. Recent bark beetle activity was light.

One habitat type, *Abies lasiocarpa/Ribes montigenum* h.t., *Ribes* phase (Pfister 1972) was found on the study area.

Average basal areas remaining after the harvest cuttings were:

| | Uncut forest | Partial cut | Clearcut |
|---|---|---|---|
| Average basal area | | | |
| ft²/acre | 141.0 | 40.0 | 6.0 |
| m²/ha | 32.4 | 9.2 | 1.4 |

Individual point samples ranged from 0 to 210 ft² of basal area per acre (0 to 48.2 m²/ha). Advance regeneration accounted for the clearcut basal area value. Partial cut treatments were somewhat atypical in that they were small half-acre (0.2-ha) clearcuts randomly scattered throughout the 5-acre (2-ha) treatment block.

## Study Design

Four study areas, one each on the Payette, Teton, Uinta, and Dixie National Forests were established with two replications of three treatments (clearcut, partial cut, and control) randomly located within each area. Engelmann spruce and subalpine fir advance regeneration from two height classes (1.0 to 4.5 ft [0.3 to 1.3 m] and 4.6 to 15.0 ft [1.4 to 4.5 m]) was sampled at 10 randomly located plots within each treatment. Sample trees met three study criteria: (1) must be closest of that species and height class to the plot center, (2) cannot be used for more than one plot, and (3) must be at least one tree height (mature stand) distance from treatment edge. Uncut control trees were sampled to determine climatic effects. We measured annual height increment of the advance regeneration to determine how it responded to release after overwood removal. Sample trees were collected and later measured in the laboratory. Stem analysis was used to accurately measure yearly height growth for the previous 15-year period—the 5-year pretreatment period and the 10-year posttreatment period. Basal discs were used to age sample trees.

We also measured total tree height, live crown length, and diameter at breast height (d.b.h.). Overstory competition was measured by two methods: (1) crown density using a spherical densiometer, and (2) volume/acre (volume/ha) and basal area/acre (basal area/ha) using a basal-area gage (10-factor).

## Analyses

Segmented regression using a special case (two-linear phase) of the general multiple phase regression technique (Johnson 1968) was used to date release response. This technique is an overall least squares solution of two fitted submodels each having their own least squares solution (Hudson 1966). Periodic height growth and time were the dependent and independent variables, respectively.

Height growth models were developed for both Engelmann spruce and subalpine fir from each of the four National Forests (Teton, Uinta, Dixie, and Payette) because Bartlet's test of homogeneity showed highly significant differences between species and forests. This was based on the dependent variable, posttreatment 10-year height growth. The standard regression model used was:

$$\hat{Y} = B_0 + B_1X_1 + B_2X_2 + \ldots B_nX_n$$

Each model was developed through step-wise regression analysis techniques using the following variables:

*Dependent Variables*

POHG = Posttreatment 10-year height growth (feet)

LNPOHG = Natural log posttreatment 10-year height growth (feet)

*Independent Variables*

PRHG = Pretreatment 5-year height growth (feet)

POBA = Posttreatment basal area (ft²/acre)

IH = Initial height (feet)

ICL = Initial crown length (feet)

ICR = Initial crown ratio $\left(\frac{\text{crown length (feet)}}{\text{total height (feet)}}\right)$

IA = Initial age

LNIH = Natural log initial height (feet)

LNICR = Natural log initial crown ratio $\left(\frac{\text{crown length (feet)}}{\text{total height (feet)}}\right)$

Initial age, height, and crown length were reconstructed using stem analysis techniques. Using step-wise regression, the F-statistic (0.01 significance level) and the improvement in $R^2$ were used to determine how much variance was explained by each of the variables entering into the model. Based on regression means and variances, a log function transformation was used to improve some models.

Although nearly all of the independent variables strengthened the regression models, 5-year pretreatment height growth and posttreatment basal area were generally the best predictors of 10-year posttreatment height growth. Fortunately, both variables are easily measured in the field and provide reasonable estimates of future height growth response. In light of this, we developed condensed models and tables using only these variables (appendix tables 2 through 5). It should be recognized, however, that the condensed models are less sensitive than the step-wise regression models shown for each of the forests in the following sections.

# RESULTS

Results of the evaluations of all four study areas—the Payette, Teton, Uinta, and Dixie National Forests—were surprisingly consistent, considering distances between the study areas. Approximately 425 north-south air miles (684 km) separated the Payette and Dixie National Forests, and 325 east-west air miles (523 km) separated the Payette and the Teton National Forests. In spite of this geographical separation, understory tree components of the four study areas were very similar, with Engelmann spruce and subalpine fir predominating. Although lodgepole pine occurred on the Teton and Payette, limber pine on the Teton, and aspen on the Dixie, the small numbers of these species were insignificant from an advance regeneration management standpoint. Therefore, these results focus entirely on advance regeneration of Engelmann spruce and subalpine fir. Included are the evaluations of the following periods: 5 years prior to harvest cutting treatments, the first 5 years after treatments, and the 6- to 10-year period after treatments.

Models were developed to show 10-year height growth release of understory spruce and subalpine fir following varying harvest cutting intensities on the four study areas. Independent variables used in the models were: 5-year pretreatment height growth, posttreatment basal area, and initial age, height, crown length, and crown ratio.

## Payette National Forest

Both spruce and subalpine fir on the Payette National Forest responded to release by increasing height growth over that of their pretreatment rate for both measurement periods—the 0- to 5- and 6- to 10-year periods. Height growth increase was greatest in clearcuts, intermedial in partial cuts, and essentially missing in uncut stands (fig. 3). Growth response was modest in the 0- to 5-year posttreatment period; but during the 6- to 10-year posttreatment period, both species in clearcuts grew about three and one-half times and in partial cuts, just over three times their pretreatment rates—both significantly greater than the controls, but not significantly different from each other.

A severe blowdown in 1969 on one partial cut created a near clearcut situation which may account for the relatively small difference in growth response between the partial cut and clearcut treatments. A minor amount of stand disturbance in the uncut controls from windthrow possibly accounted for minor increases in height growth in the 6- to 10-year posttreatment period.

The Payette was one of two study sites where Engelmann spruce height growth responded about equal to or better than subalpine fir in both the 0- to 5- and 6- to 10-year posttreatment periods (fig. 3). Both species gradually increased in height growth as time since treatment on both partial cuts and clearcuts increased.

Segmented regression results (fig. 4, 5) show upward height growth trends at the end of the 10-year posttreatment period. We have nothing in these data to predict when this upward trend will level off.

Subalpine fir responded to release sooner than Engelmann spruce (fig. 4, 5). Segmented regression analyses show that it took fir 1 to 2 years and spruce 3 to 5 years to accelerate height growth. The only exception occurred in the partial cut where the upper height class (4.6 to 15.0 ft [1.4 to 4.5 m] tall) of spruce responded in a pattern similar to that of fir.

Subalpine fir of both height classes (1.0 to 4.5 ft [0.03 to 1.37 m] and 4.6 to 15.0 ft [1.38 to 4.57 m]) responded at about the same time, but grew more and faster than the shorter fir on both clearcuts and partial cuts. Engelmann spruce response patterns were similar to those of fir, but the time of response was inconsistent between tree sizes and stand treatments. Spruce height growth in the taller height class was greater but took place at rates similar to those of the shorter height class.

Some trees, particularly subalpine fir, exhibited a decline in height growth for a year or two after release from overwood competition (fig. 4, 5). Upon adjustment to the

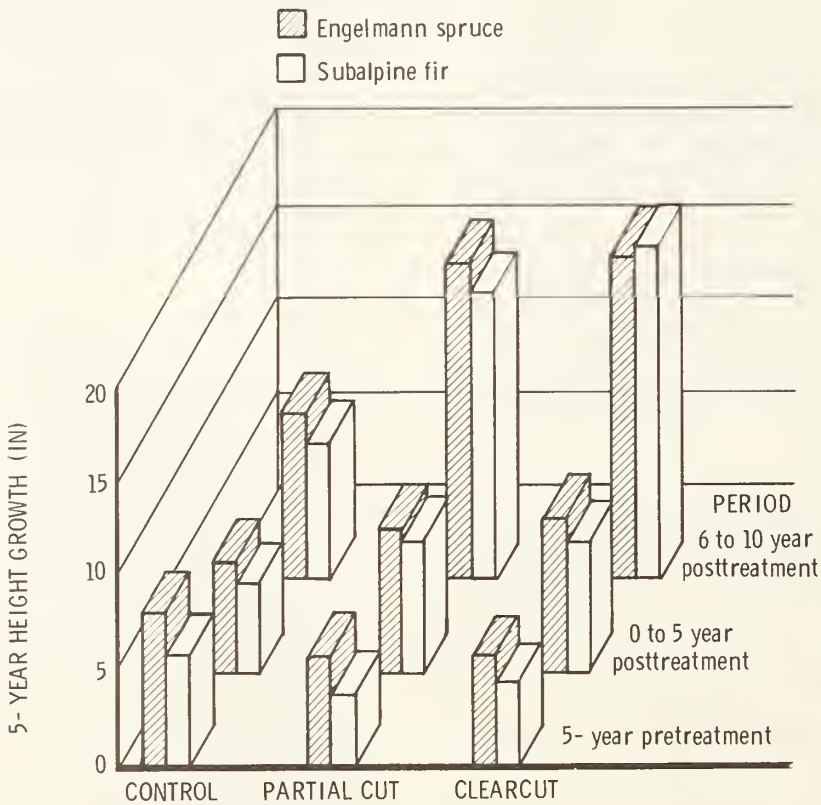


Figure 3.—Periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 0- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, partial cuts, and clearcuts on the Payette National Forest.

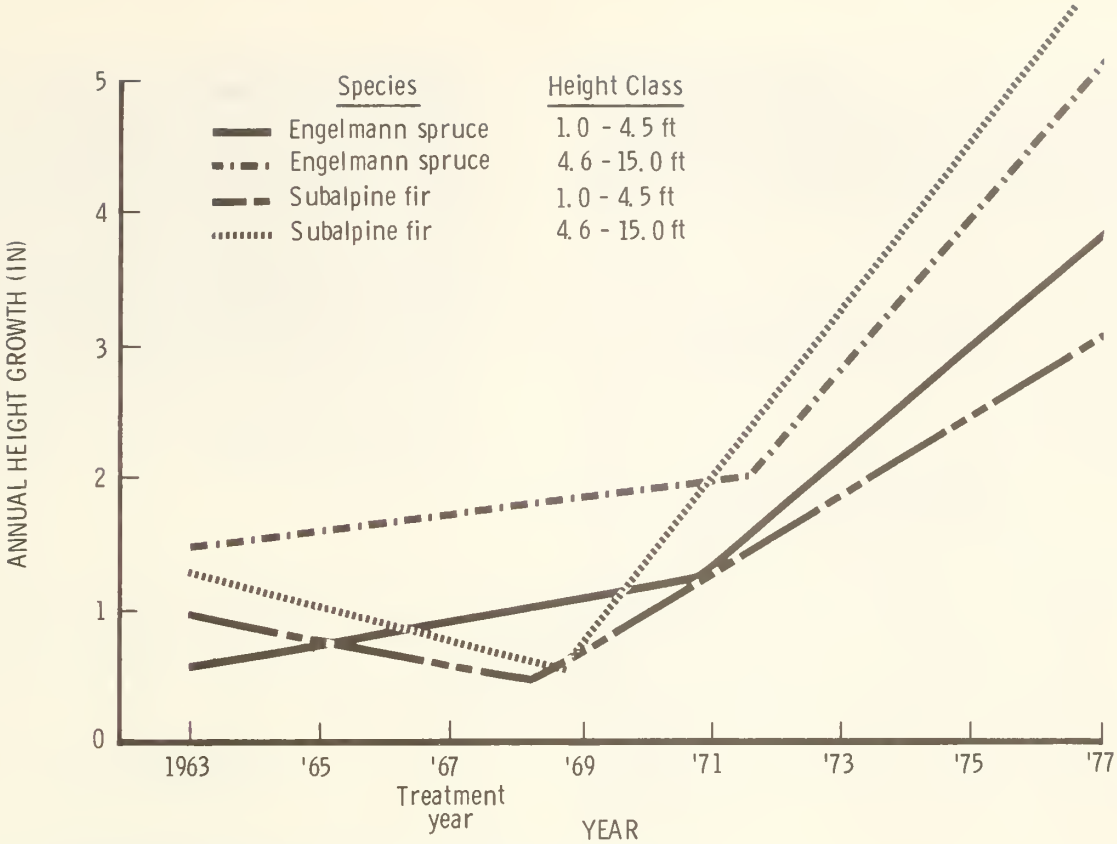


Figure 4.—Annual height growth of Engelmann spruce and subalpine fir on clearcuts on the Payette National Forest by year and height class. Lines are plotted from segmented regression values.

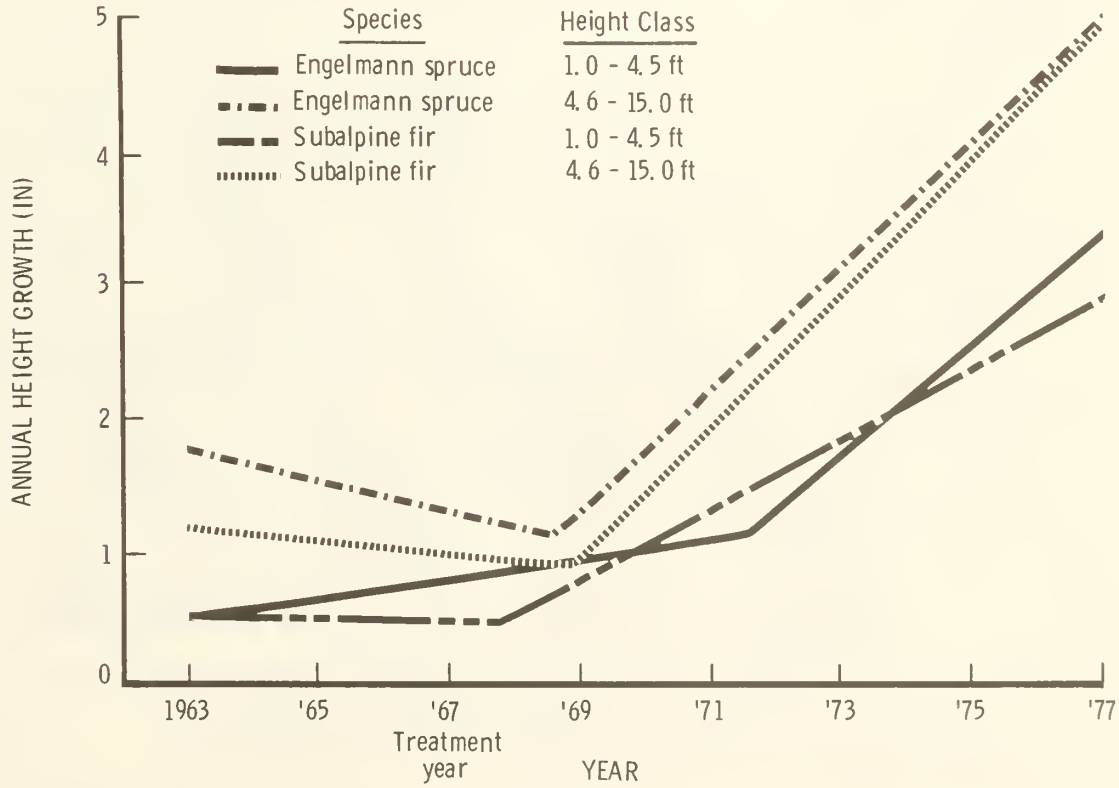


Figure 5.—Annual height growth of Engelmann spruce and subalpine fir on partial cuts on the Payette National Forest by year and height class. Lines are plotted from segmented regression values.

change in environment, however, the trees regained and subsequently exceeded their pretreatment growth rates.

Using variables described in the analysis section, height growth release models predicting 10-year post-treatment height growth for Engelmann spruce and subalpine fir on the Payette are:

*Engelmann spruce:*

$$POHG = 1.7975 + 0.2078PRHG - 0.3207IH - 0.0167POBA + 0.2622ICL$$
$$R^2 = 0.40 \qquad SSE = 0.9136 \qquad n = 79$$

*Subalpine fir:*

$$LNPOHG = 0.6188 - 0.0111POBA + 0.0534PRHG - 0.0041ICR$$
$$R^2 = 0.16 \qquad SSE = 0.6066 \qquad n = 77$$

## Teton National Forest

Both Engelmann spruce and subalpine fir on the Teton National Forest responded significantly to release. Post-treatment height growth response was greatest in clear-cuts, intermediate in partial cuts, and essentially none in the uncut controls (fig. 6). During the 6- to 10-year post-treatment period, trees in the clearcut grew an average of over four times their pretreatment growth and about twice that of their 0- to 5-year posttreatment period. Trees in the partial cut grew significantly less, about half that of trees in the clearcuts during the 6- to 10-year period, but still doubled their own pretreatment rate. A minor amount of windthrow in the controls prompted a slight increase of height growth in the 6- to 10-year period ove the pretreatment period.

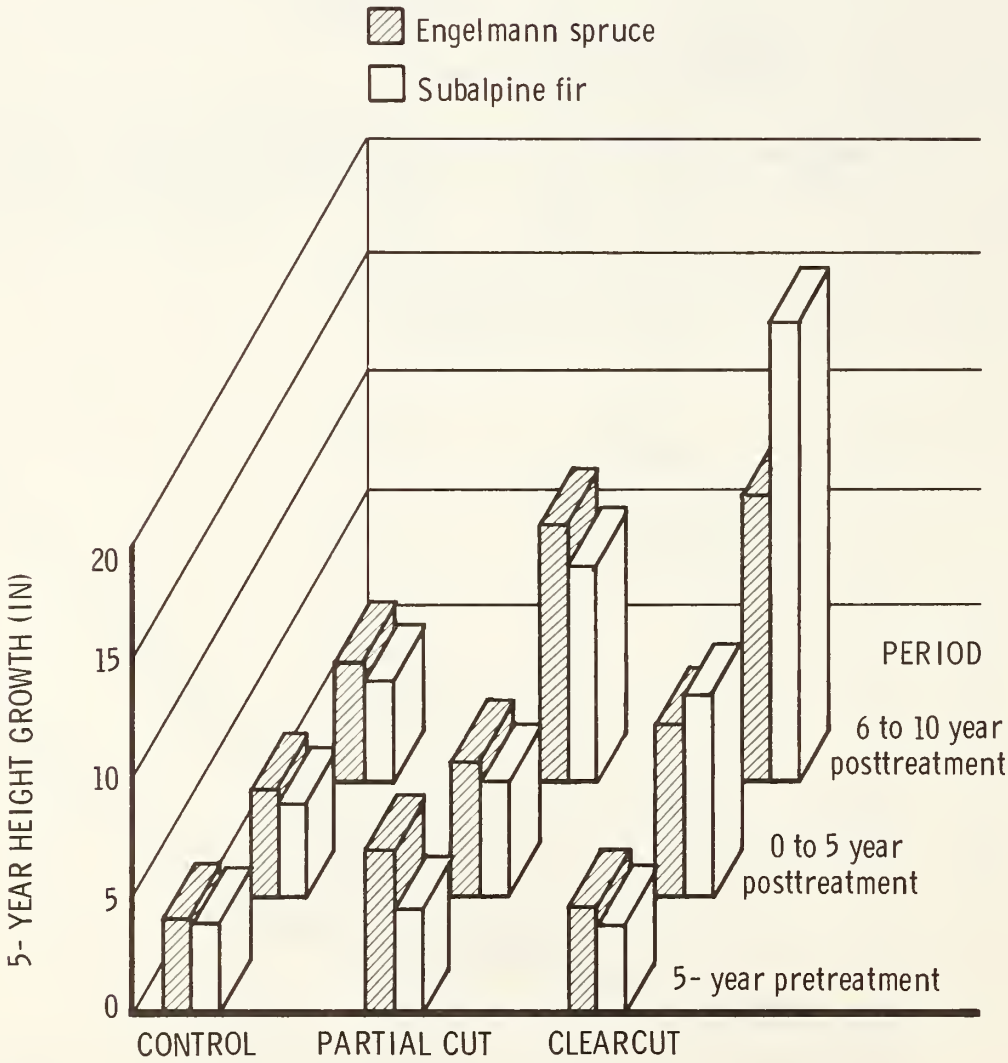


Figure 6.—Periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 0- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, partial cuts, and clearcuts on the Teton National Forest.

Subalpine fir outgrew Engelmann spruce in height on clearcuts, but within each height class, they responded about the same on partial cuts (fig. 7, 8). Fir responded the first year after clearcutting, spruce 3 to 4 years later. This relationship was not apparent on partial cuts where taller trees (4.6 to 15.0 ft [1.40 to 4.57 m]) of both species responded 2 to 4 years later than shorter trees (1.0 to 4.5 ft [0.3 to 1.37 m]).

Taller trees of both species generally responded more than smaller trees. The substantial differences in growth response between clearcuts and partial cuts held true for both large and small trees.

As in the Payette, the upward trend in height growth was still apparent the 10th year of the study, and we do not know when this will level off.

Using variables described in the analysis section, height growth release models predicting 10-year post-treatment height growth for Engelmann spruce and subalpine fir on the Teton are:

*Engelmann spruce:*

$$POHG = 0.3379 + 0.1430PRHG - 0.0057POBA + 0.0135ICR$$
$$R^2 = 0.58 \qquad SSE = 0.7495 \qquad n = 71$$

*Subalpine fir:*

$$LNPOHG = 0.4697 - 0.0087POBA + 0.1644LNIH + 0.0253PRHG$$
$$R^2 = 0.34 \qquad SSE = 0.6288 \qquad n = 66$$

## Uinta National Forest

Engelmann spruce and subalpine fir on the Uinta National Forest responded much like those on the Teton National Forest, with only modest increases in height growth in the 0- to 5-year posttreatment period, but significant increases in height growth during the 6- to 10-year posttreatment period over that of their pretreatment growth (fig. 9). Average growth of spruce and fir increased 5 to 6 times that of their pretreatment growth on both clearcuts and partial cuts. It should be noted, however, that pretreatment growth here was very low—only about an inch (2.5 cm) a year. In the 0- to 5-year posttreatment period, there were only minor increases in height growth. Trees on the clearcut grew the most; those in the partial cut were next in growth. Tree growth in the uncut controls remained essentially static.

Subalpine fir height growth was greater than Engelmann spruce on both clearcuts and partial cuts, particularly in the 6- to 10-year post-treatment period (fig. 9). This difference appears related to the time lag needed by the taller trees (4.6 to 15.0 ft [1.4 to 4.6 m]) to adjust to their new environment (fig. 10, 11). The shorter trees (1.0 to 4.6 ft [0.3 to 1.37 m]) show this relation as a function of slope differences. The pattern of response time with treatment and species showed no consistency. Response time ranged from 1 to 5 years after release. The larger trees responded generally later than smaller trees, but their overall height growth was more on both cutting treatments.

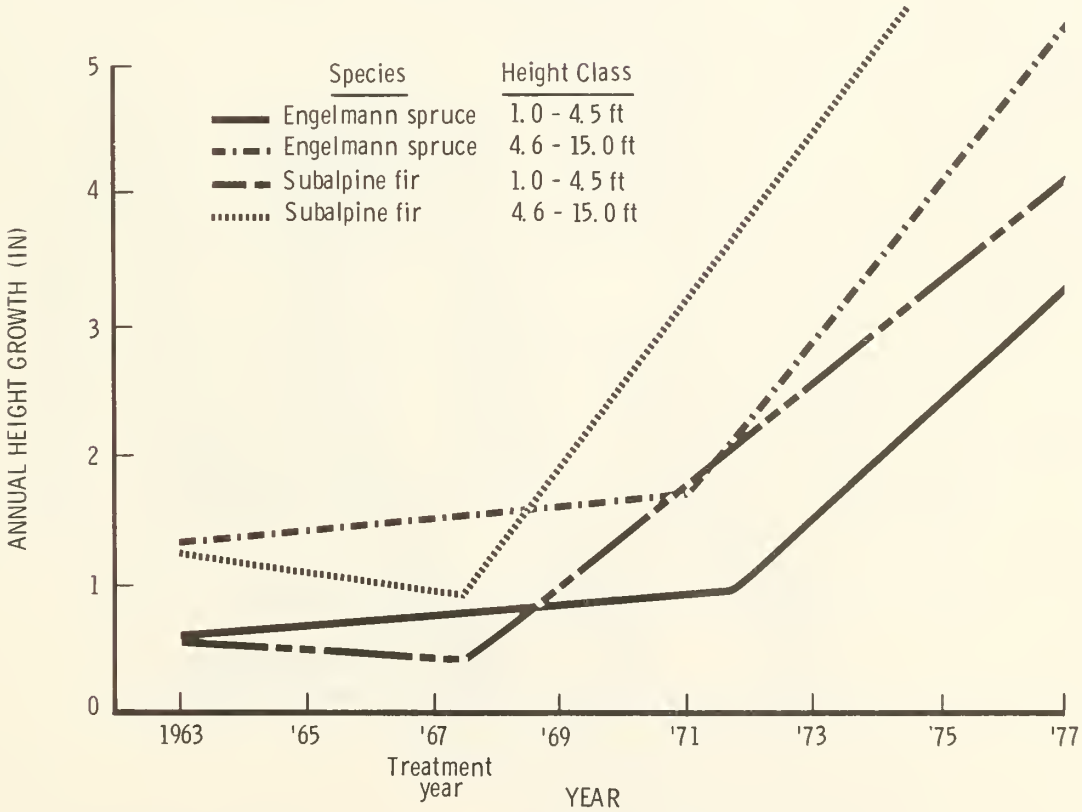


Figure 7.—Annual height growth of Engelmann spruce and subalpine fir on clearcuts on the Teton National Forest by year and height class. Lines are plotted from segmented regression values.

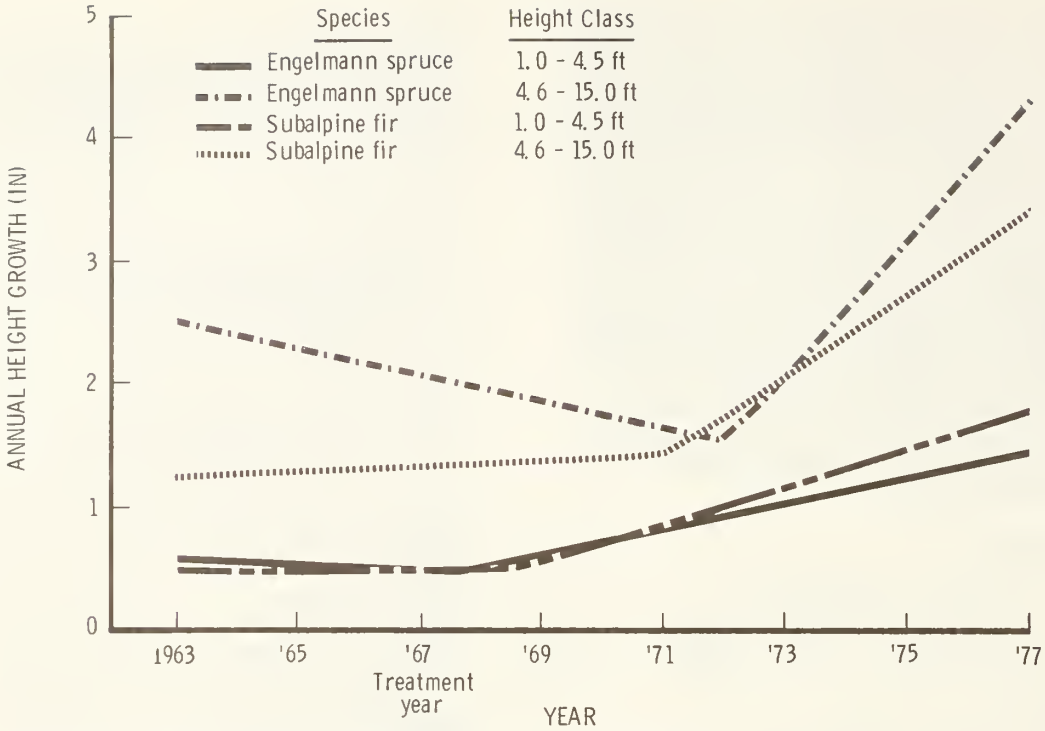


Figure 8.—Annual height growth of Engelmann spruce and subalpine fir on partial cuts on the Teton National Forest by year and height class. Lines are plotted from segmented regression values.

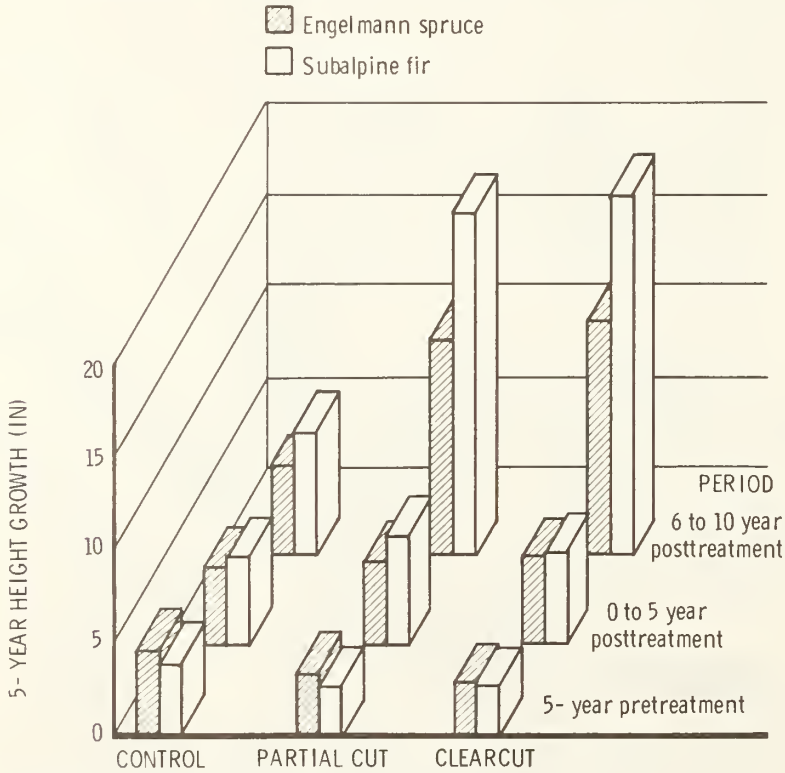


Figure 9.—Periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 0- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, partial cuts, and clearcuts on the Uinta National Forest.

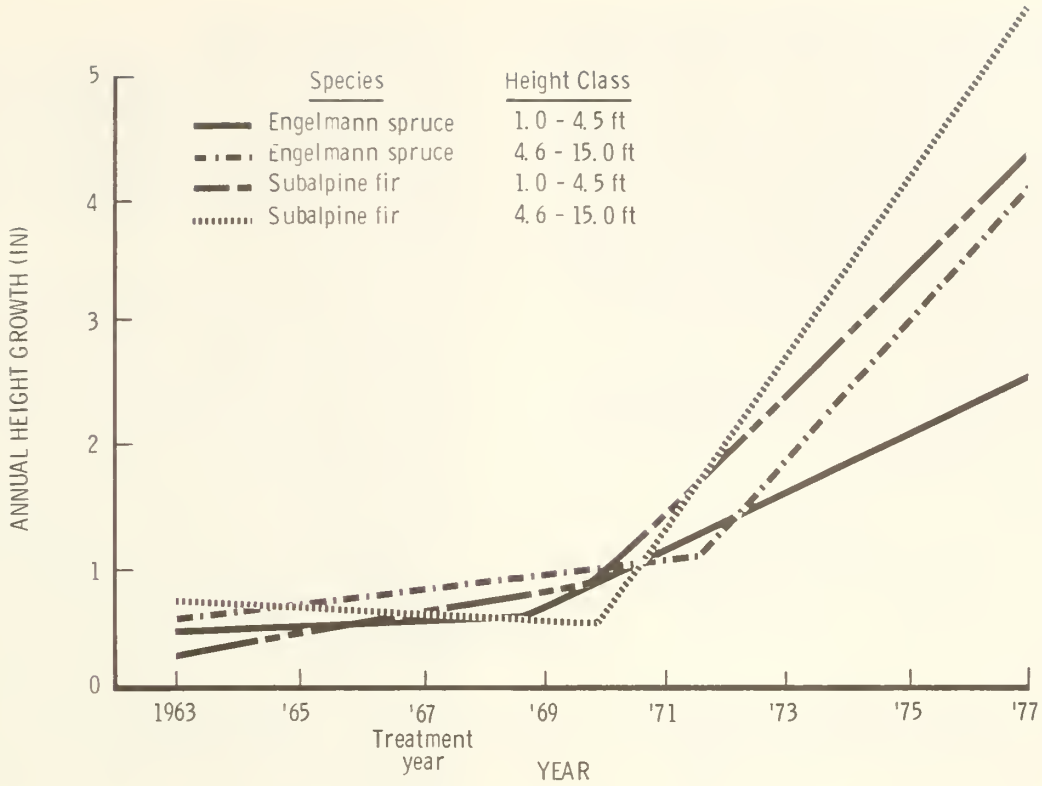


Figure 10.—Annual height growth of Engelmann spruce and subalpine fir on clearcuts on the Uinta National Forest by year and height class. Lines are plotted from segmented regression values.

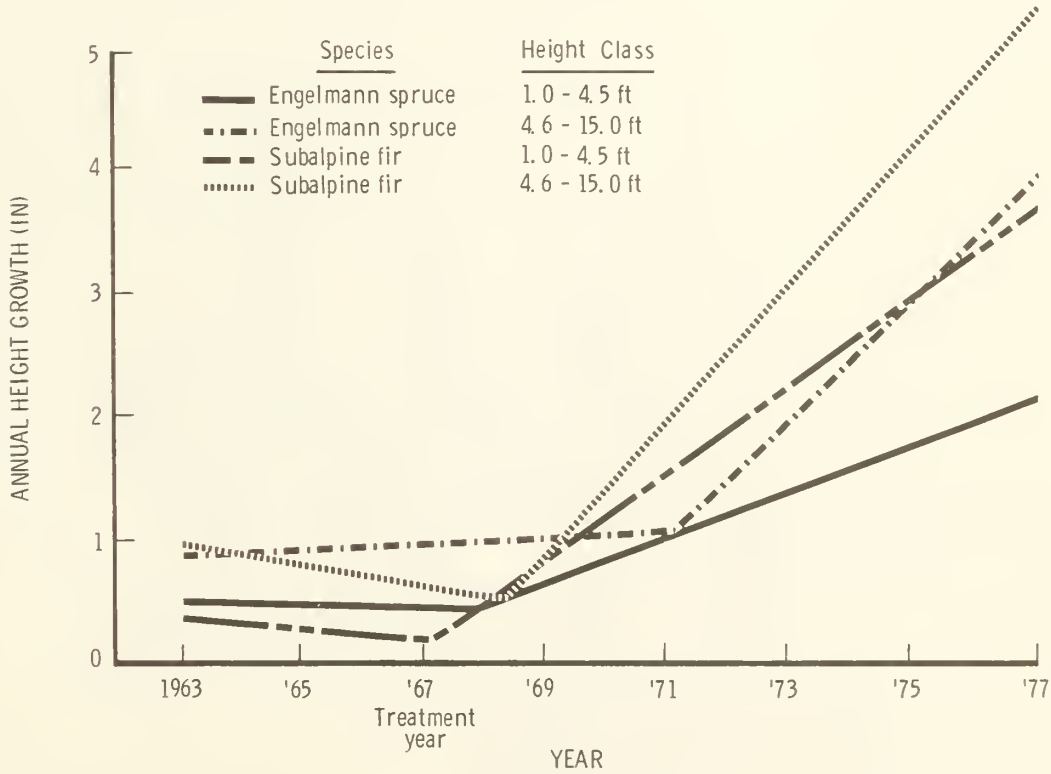


Figure 11.—Annual height growth of Engelmann spruce and subalpine fir on partial cuts on the Uinta National Forest by year and height class. Lines are plotted from segmented regression values.

The generally upward trend in height growth at the end of the 10-year period showed no signs of decelerating, and these data provide no indication of how long that upward trend will continue.

The nature of the cuttings on the Uinta study area likely explains why the differences between the clearcut and partial cut treatments were so small. The clearcuttings were conventional, but the partial cuttings are probably best described as group selection rather than single tree selection. The sample points were within the small group cuttings. These small group cuts created environmental conditions more like small clearcuts than of single tree selection.

Using variables described in the analysis section, height growth release models predicting 10-year posttreatment height growth for Engelmann spruce and subalpine fir on the Uinta are:

*Engelmann spruce:*

$$POHG = 1.0574 + 0.1391PRHG - 0.0073POBA + 0.0921ICL$$
$$R^2 = 0.27 \qquad SSE = 0.7339 \qquad n = 79$$

*Subalpine fir:*

$$LNPOHG = 0.4621 - 0.0072IA + 0.1360LNIH + 0.1477LNICR$$
$$R^2 = 0.11 \qquad SSE = 0.4867 \qquad n = 77$$

## Dixie National Forest

Engelmann spruce and subalpine fir responded significantly in height growth during the 6- to 10-year posttreatment period following both partial cutting and clearcutting on the Dixie National Forest (fig. 12). Trees that were averaging 2 to 3 inches (5 to 8 cm) annual height growth under pretreatment conditions averaged over 6 inches (15 cm) annually during the 6- to 10-year posttreatment period.

Trees within clearcuts grew significantly faster than trees in partial cuts, more than doubling their pretreatment height growth, while those in the partial cut increased their height growth about 50 percent. Average height growth during the 0- to 5-year posttreatment period was about the same or slightly less than the pretreatment growth on both cutting treatments. Dixie site conditions placed rigorous stresses on the trees while they adjusted to their new environment following treatment. Trees in uncut controls remained essentially static in height growth for the 15-year measurement period.

Subalpine fir height growth was slightly greater than Engelmann spruce, but the differences were not significant (fig. 12). Delays in response of the trees were more a function of tree size than species ( fig. 13, 14). Small trees (1.0 to 4.5 ft [0.3 to 1.37 m]) of both species responded the first year on clearcuts. Small spruce on the partial cuts exhibited no significant release time. Larger trees (4.6 to 15.0 ft [1.4 to 4.57 m]) of both species delayed about 4 years on clearcuts and 2 years on partial cuts before they responded. During that 2- to 4-year delay period, they

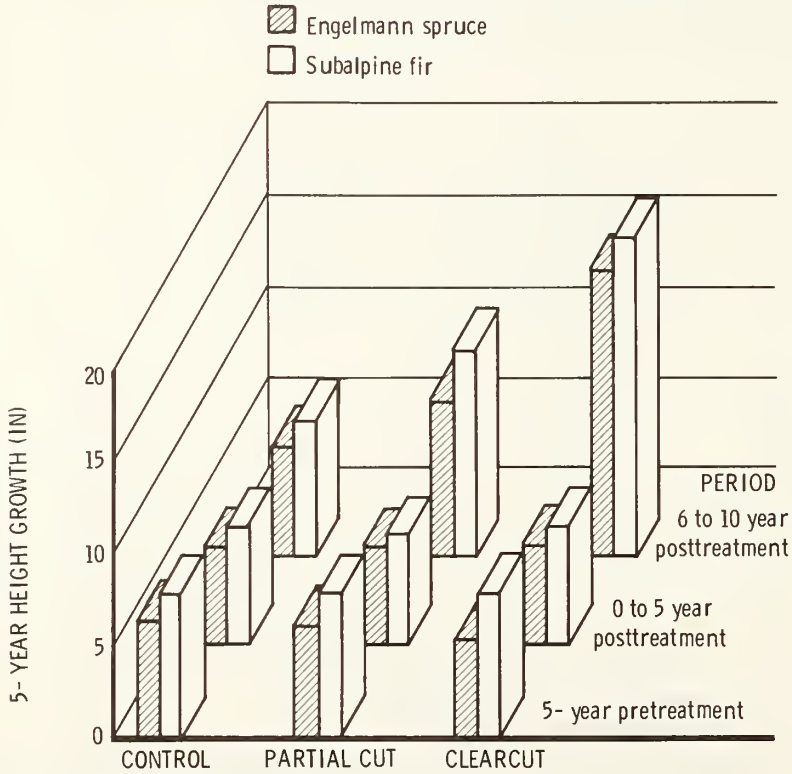


Figure 12.—Periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 0- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, partial cuts, and clearcuts on the Dixie National Forest.

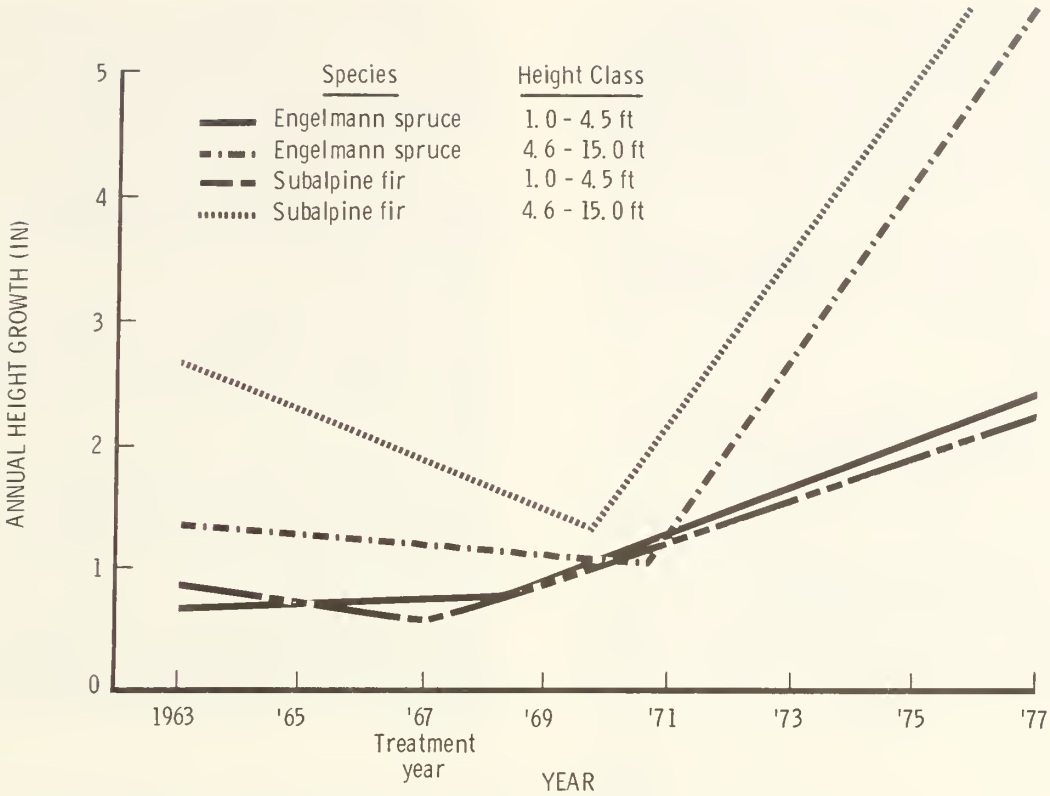


Figure 13.—Annual height growth of Engelmann spruce and subalpine fir on clearcuts on the Dixie National Forest by year and height class. Lines are plotted from segmented regression values.

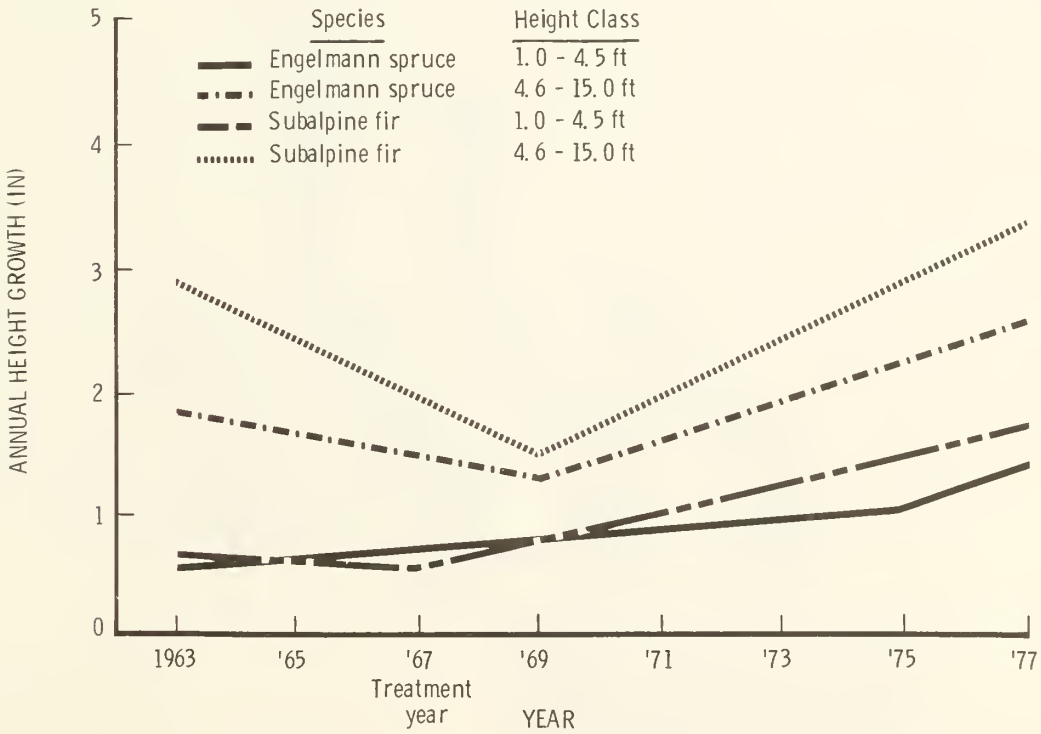


Figure 14.—Annual height growth of Engelmann spruce and subalpine fir on partial cuts on the Dixie National Forest by year and height class. Lines are plotted from segmented regression values.

grew slower in height than they had prior to cutting. After the taller trees of both species adjusted to their new environment, they grew significantly faster than their shorter counterparts on both clearcuts and partial cuts.

The strong upward trend in height growth at the end of the 10-year posttreatment period is encouraging. The data, however, provide no basis for extrapolation since a leveling-off trend can be expected. When? is the question.

Using variables described in the analysis section, height growth release models predicting 10-year posttreatment height growth for Engelmann spruce and subalpine fir on the Dixie are:

*Engelmann spruce:*

$$LNPOHG = 0.3652 - 0.0056POBA + 0.0608PRHG - 0.0066IA + 0.2315\ LNIH$$

$R^2 = 0.58$ SSE = 0.4587 n = 78

*Subalpine fir:*

$$LNPOHG = -1.8550 + 0.0483PRHG + 0.0052IA + 0.3557LNICR$$

$R^2 = 0.41$ SSE = 0.5366 n = 73

## GENERAL SUMMARY AND DISCUSSION

Height growth response of both Engelmann spruce and subalpine fir understory trees exhibited a similar pattern throughout all four study areas. Their overall summary (fig. 15) shows the same general trends. From this summary the following generalizations can be made:

1. Both species responded to release by substantially increasing their height growth—greatest in clearcuts, intermedial in partial cuts, and essentially none in uncut controls—a direct relationship to the amount of residual overwood (fig. 15).

2. Trees on clearcuts grew an average of nearly four times faster during the 6- to 10-year posttreatment period than before treatment. This compares with Gordon's (1973) findings in northern California. Trees in partial cuts averaged about two and one-half times their pretreatment growth.

3. Although both spruce and fir responded by increasing their height growth during the first 5 years after treatment, increases during this period were relatively minor compared to those in the 6- to 10-year period. This also compares with Gordon's (1973) findings for white and red fir.

4. Prior to release, spruce and fir height growth, with only minor exceptions, was about the same on all areas. Subalpine fir responded sooner, however, than Engelmann spruce on both partial cuts and clearcuts.

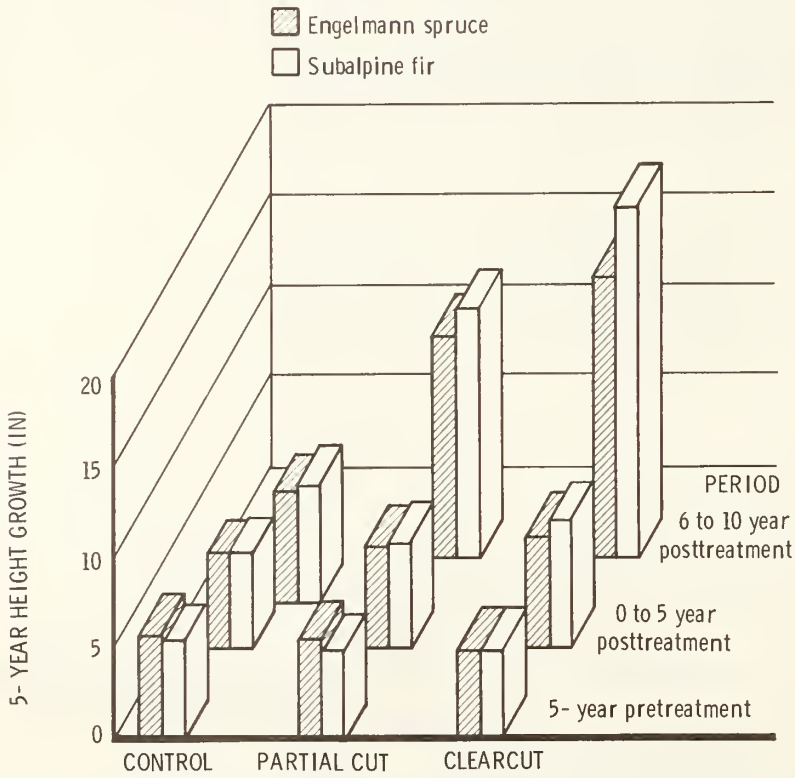


Figure 15.—Average periodic height growth of understory Engelmann spruce and subalpine fir 5-year pretreatment, 0- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, partial cuts, and clearcuts for the combined Payette, Teton, Uinta, and Dixie National Forests.

5. Height growth release began from 1 to 7 years after treatment, with fir response delayed an average of 1 to 2 years, and spruce 3 to 4 years (table 1).

6. Taller trees (4.6 to 15.0 ft [1.4 to 4.57 m]) responded later than shorter trees (1.0 to 4.5 ft [0.3 to 1.37 m])—fir about 1 year later and spruce a little less than a year later than their shorter counterparts.

7. Spruce and fir height growth of both height classes and on both cutting treatments was still accelerating on all four areas 10 years after treatment. An obvious unknown is how long the acceleration in growth will continue and when and at what rate it will level off. This will be a function of site and stand conditions and tree potential. Advance regeneration of subalpine fir and Engelmann spruce in British Columbia grew substantially faster than some of its natural regeneration counterparts 21 years after site treatment (Herring and McMinn 1980). This comparison, however, was somewhat clouded because natural regeneration occurred where excessive scarification had deteriorated the site. Based on observations by Roe and DeJarnette (1965), increased height growth may continue for at least 25 to 30 years. There is some European evidence that spruce and fir "can endure crown competition over several decades without it inhibiting their later growing capabilities" (Assmann 1970). Assmann goes on to present some response data that indicate that once released, spruce and fir height growth essentially parallels the growth of trees that have been free to grow.

8. A factor, not well identified in this study, is the long-term effect of logging damage. Although some of our sample trees were damaged during logging, we found no evidence of rot in our evaluations. Ten years may be insufficient time, however, for rots to become apparent under these cold conditions.

9. Understory tree height growth within the uncut controls remained virtually constant on all four study areas during the observed 15-year period. Some control trees showed a slight decline in growth over time, and some a slight increase where there had been minor disturbances, but both of these exceptions were minor.

10. Average ages of the understory trees were much higher than one would expect for trees under 15 ft (4.57 m) tall—spruce averaged 68 years and fir 74 years on the four study areas, with a total age range of 5 to 195. Sixty-eight percent of the spruce and fir sampled were in the age range between 31 to 104 years and 38 to 109 years, respectively. This compares well with the age and successional data from earlier work in southern Utah (Hanley and others 1975). Height and age were poorly correlated.

11. With the best combinations of area, treatment, and species, annual height growth the 10th year after treatment averaged about 6 inches (15.2 cm). The overall average the 10th year was about 4.5 inches (11.4 cm) on clearcuts and 3.2 inches (8.13 cm) on partial cuts. As pointed out earlier, however, height growth was still increasing at the end of the observation period. We do not have data for comparing this advanced regeneration growth with that of subsequent natural or artificial regeneration from the immediate study areas. Hanley and Pfister,[2] however, measured natural and planted regeneration on the Dixie National Forest in the proximity of our study area. Here, 8-year-old plantations of spruce have reached 2 ft (0.61 cm) in height and current annual increments are approaching 6 inches (15.2 cm). Natural regeneration in the same period had reached a height of 1 ft (30.5 cm) with annual increments of about 3 inches (7.6 cm). Nearby, on the Fishlake National Forest, 5-year-old planted spruce averaged 20 inches (51 cm) in height.[3]

[2]Hanley, Donald P., and Robert D. Pfister. Germination and seedling survival of Engelmann spruce on the Dixie National Forest. [In process.]

[3]Data from files of USDA Forest Service, Intermountain Region, Division of Timber Management, Ogden, Utah.

## MANAGEMENT IMPLICATIONS

Nearly all mature spruce-fir forests have an understory of advance regeneration that some managers regard as a hindrance to, and others regard as their salvation for, posttreatment management. As Roe and others (1970) concluded, advance regeneration should be evaluated before harvesting to determine whether it qualifies as acceptable growing stock and has management potential. One of the unknowns has been the response potential of these understory trees. This study begins to help define this response for the first 10 years after harvesting. It reports that these understory trees do show substantial response after they have adjusted to their new environment; that they respond in relation to the amount of residual overwood; that their previous 5-year's growth tells much about their response potential; that they are probably a lot older than thought; and that even though height growth increases dramatically percentage-wise, their absolute growth, even after 10 years of release, is modest.

Some advantages of using advance regeneration for at least part of the new stand after harvest cutting are:

1. It serves as immediate growing stock.
2. It provides shade needed for supplemental natural and artificial regeneration.
3. It may provide sufficient continuity of "green" forest to help meet wildlife cover and esthetic objectives.
4. Soil protection is afforded by retaining at least some forest cover.
5. Time needed to grow merchantable-sized trees may be reduced.
6. It reduces the amount of site preparation needed for subsequent natural and artificial regeneration.
7. Species diversity may be enhanced.

Some disadvantages of featuring advance regeneration in management are:

1. Logging damage to the advance regeneration predisposes it to long-term disease problems.
2. Subalpine fir is usually the predominant advance regeneration, but has more disease and insect problems and less management potential than spruce.
3. Advance regeneration is already physiologically old and thus prone to insect and disease problems associated with old age.
4. Featuring advance regeneration often encourages disgenic practices.
5. It may shortsightedly be used on sites where more intensive management practices are justified.
6. Harvesting costs are increased because of the need to protect the advance regeneration.
7. Site preparation needed for subsequent regeneration is made more difficult.

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# APPENDIX

Table 1.—Average number of years after harvesting before height growth response started by harvest treatment, species, and height class

| Treatment | Species | Height class: 1.0 to 4.5 ft (0.3 to 1.31 m) | Height class: 4.6 to 15.0 ft (1.4 to 4.5 m) | Average |
|---|---|---|---|---|
| | | *Years to respond* | | |
| Clearcut | Spruce | 2.8 | 4.3 | 3.6 |
| | Fir | 1.2 | 1.9 | 1.6 |
| Partial cut | Spruce | 3.4 | 3.1 | 3.2 |
| | Fir | 0.7 | 2.3 | 2.5 |
| | Average | 2.0 | 2.9 | 2.5 |

Table 2.—Ten-year height growth projections of released understory spruce and fir following harvest cutting on the Payette National Forest[1] [2]

| Posttreatment basal area | Five-year pretreatment height growth (ft): 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 |
|---|---|---|---|---|---|---|---|---|
| *Ft²* | *Feet* | | | | | | | |
| | | | | **Engelmann Spruce** | | | | |
| 0 | 2.0 | 2.4 | 2.9 | 3.3 | 3.7 | 4.1 | *4.5* | *5.0* |
| 40 | 1.3 | 1.7 | 2.2 | 2.6 | 3.0 | 3.4 | *3.8* | *4.3* |
| 80 | .6 | 1.0 | 1.5 | 1.9 | 2.3 | 2.7 | *3.2* | *3.6* |
| 120 | — | *.4* | *.8* | *1.2* | *1.6* | *2.0* | *2.5* | *2.9* |
| 160 | — | — | *.1* | *.5* | *.9* | *1.3* | *1.8* | *2.2* |
| $Y = 1.5979 + 1.6838X_1 - 0.0174X_2$ | | | | ($R^2 = 0.28$) | | | | (SSE = 0.99) |
| | | | | **Subalpine Fir** | | | | |
| 0 | 2.0 | 2.3 | 2.5 | 2.8 | 3.0 | *3.3* | *3.5* | *3.8* |
| 40 | 1.5 | 1.8 | 2.0 | 2.3 | 2.5 | *2.8* | *3.0* | *3.3* |
| 80 | 1.0 | 1.2 | 1.5 | 1.7 | 2.0 | *2.2* | *2.5* | *2.8* |
| 120 | *.5* | *.7* | *1.0* | *1.2* | *1.5* | *1.7* | *2.0* | *2.2* |
| 160 | — | *.2* | *.5* | *.7* | *1.0* | *1.2* | *1.5* | *1.7* |
| $Y = 1.7867 + 1.0013X_1 - 0.0130X_2$ | | | | ($R^2 = 0.10$) | | | | (SSE = 1.04) |

[1]Y = 10-year posttreatment height growth, feet.
$X_1$ = pretreatment 5-year height growth, feet.
$X_2$ = posttreatment basal area, square feet.
[2]Values in italics are outside the range of data.

Table 3.—Ten-year height growth projections of released understory spruce and fir following harvest cutting on the Teton National Forest[1] [2]

| Posttreatment basal area | Five-year pretreatment height growth (ft) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 |
| *Ft²* | *Feet* | | | | | | | |
| | | | | **Engelmann Spruce** | | | | |
| 0 | 1.4 | 1.9 | 2.4 | 2.8 | 3.3 | 3.8 | 4.2 | 4.7 |
| 40 | 1.2 | 1.6 | 2.1 | 2.6 | 3.0 | 3.5 | 4.0 | 4.4 |
| 80 | .9 | 1.4 | 1.9 | 2.3 | 2.8 | 3.2 | 3.7 | 4.2 |
| 120 | .7 | 1.1 | 1.6 | 2.1 | 2.5 | 3.0 | 3.4 | 3.9 |
| 160 | *.4* | *.9* | *1.3* | *1.8* | *2.3* | *2.7* | *3.2* | *3.7* |
| $Y = 0.9762 + 1.8590X_1 - 0.0065X_2$ | | | | ($R^2 = 0.54$) | | | | (SSE = 0.78) |
| | | | | **Subalpine Fir** | | | | |
| 0 | 2.2 | 2.4 | 2.7 | 2.9 | 3.1 | 3.4 | *3.6* | *3.9* |
| 40 | 1.7 | 1.9 | 2.2 | 2.4 | 2.6 | 2.9 | *3.1* | *3.4* |
| 80 | 1.2 | 1.4 | 1.7 | 1.9 | 2.1 | 2.4 | *2.6* | *2.9* |
| 120 | .7 | .9 | 1.2 | 1.4 | 1.7 | 1.9 | *2.1* | *2.4* |
| 160 | .2 | .4 | .7 | .9 | 1.2 | 1.4 | *1.6* | *1.9* |
| $Y = 1.9556 + 0.9473X_1 - 0.0124X_2$ | | | | ($R^2 = 0.30$) | | | | (SSE = 1.00) |

[1]Y = 10-year posttreatment height growth, feet.
$X_1$ = pretreatment 5-year height growth, feet.
$X_2$ = posttreatment basal area, square feet.
[2]Values in italics are outside the range of data.

Table 4.—Ten-year height growth projections of released understory spruce and fir following harvest cutting on the Uinta National Forest[1] [2]

| Posttreatment basal area | Five-year pretreatment height growth (ft) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 |
| *0800 Ft²* | *Feet* | | | | | | | |
| | | | | **Engelmann Spruce** | | | | |
| 0 | 1.6 | 2.1 | 2.6 | 3.2 | 3.7 | *4.2* | *4.7* | *5.2* |
| 40 | 1.4 | 1.9 | 2.4 | 2.9 | 3.4 | *3.9* | *4.4* | *4.9* |
| 80 | 1.1 | 1.6 | 2.1 | 2.6 | 3.1 | *3.6* | *4.1* | *4.6* |
| 120 | .8 | 1.3 | 1.8 | 2.3 | 2.8 | *3.3* | *3.8* | *4.3* |
| 160 | *.5* | *1.0* | *1.5* | *2.0* | *2.5* | *3.0* | *3.6* | *4.1* |
| $Y = 1.1268 + 2.0282X_1 - 0.0070X_2$ | | | | ($R^2 = 0.24$) | | | | (SSE = 0.74) |
| | | | | **Subalpine Fir[3]** | | | | |

[1]Y = 10-year posttreatment height growth, feet.
$X_1$ = pretreatment 5-year height growth, feet.
$X_2$ = posttreatment basal area, square feet.
[2]Values in italics are outside the range of data.
[3]Neither pretreatment height growth or posttreatment basal area were good predictors of subalpine fir response on the Uinta. See the RESULTS section for the equation that best describes this response.

Table 5.—Ten-year height growth projections of released understory spruce and fir following harvest cutting on the Dixie National Forest[1] [2]

| Posttreatment basal area | Five-year pretreatment height growth (ft) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 |
| *Ft²* | *Feet* | | | | | | | |
| | | | | **Engelmann Spruce** | | | | |
| 0 | 1.7 | 2.0 | 2.2 | 2.5 | 2.8 | 3.1 | *3.4* | *3.7* |
| 40 | 1.4 | 1.7 | 2.0 | 2.3 | 2.5 | 2.8 | *3.1* | *3.4* |
| 80 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | 2.5 | *2.8* | *3.1* |
| 120 | .8 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | *2.6* | *2.8* |
| 160 | .6 | .8 | 1.1 | 1.4 | 1.7 | 2.0 | *2.3* | *2.6* |
| $Y = 1.3830 + 1.1480X_1 - 0.0070X_2$ | | | | ($R^2 = 0.41$) | | | | (SSE = 0.73) |
| | | | | **Subalpine Fir** | | | | |
| 0 | 1.4 | 1.7 | 2.0 | 2.3 | 2.6 | 2.9 | 3.2 | 3.5 |
| 40 | 1.3 | 1.6 | 1.9 | 2.2 | 2.5 | 2.8 | 3.1 | 3.5 |
| 80 | 1.2 | 1.6 | 1.9 | 2.2 | 2.5 | 2.8 | 3.1 | 3.4 |
| 120 | 1.2 | 1.5 | 1.8 | 2.1 | 2.4 | 2.7 | 3.0 | 3.3 |
| 160 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | 2.6 | 2.9 | 3.2 |
| $Y = 1.0972 + 1.2160X_1 - 0.0019X_2$ | | | | ($R^2 = 0.35$) | | | | (SSE = 1.03) |

[1]Y = 10-year posttreatment height growth, feet.
$X_1$ = pretreatment 5-year height growth, feet.
$X_2$ = posttreatment basal area, square feet.
[2]Values in italics are outside the range of data.

McCaughey, Ward W., and Wyman C. Schmidt.
1982. Understory tree release following harvest cutting in spruce-fir forests of the Intermountain West. USDA For. Serv. Res. Pap. INT-285, 19 p. Intermt. Forest and Range Experiment Station, Ogden, Utah 84401.

This paper describes 10-year response of understory Engelmann spruce and subalpine fir following partial cutting and clearcutting of the overwood. This study in forests of Idaho, Wyoming, and Utah demonstrated that both spruce and fir understory trees responded to release by increasing in height growth slightly in the first 5-year, and substantially in the second 5-year post-harvest period. Trees responded more in the clearcuts than in the partial cuts.

KEYWORDS: *Picea engelmannii, Abies lasiocarpa,* advance regeneration, release response, understory tree release, overwood removal

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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